# The historical influence of fire on the flammability of subalpine Snowgum forest and woodland

Philip Zylstra

Centre for Environmental Risk Management of Bushfires, University of Wollongong, NSW 2522. Email: pzylstra@uow.edu.au

**Abstract**

It is widely assumed that regardless of the community in question, recently burnt forests are less flammable than long-unburnt areas, so that the fire–flammability feedback is negative. An alternative hypothesis has been proposed for Snowgum forest/woodland based on deterministic fire behaviour modelling, describing a positive feedback where mature forests are significantly less flammable than more recently burnt areas. To test this, the relative area burnt by wildfire was examined for 53 years of mapped fire history in 190 000 ha of subalpine Snowgum across the Australian Alps National Parks in south-eastern Australia. Results supported the deterministic modelling, demonstrating that where forest has been burnt in the previous 14 years, subsequent fires have burnt 2.3 times as much area as they did in older forests ($p = 0.05$). These findings provide validation for the modelling and suggest far reaching consequences for subalpine and alpine areas in the context of a warming climate. (*The Victorian Naturalist* 130 (6) 2013, 232–239)

**Keywords:** fire behaviour, flammability, risk, sub-alpine

## Introduction

The relationship between time since fire and the flammability of unique plant communities has important implications in the context of expected increases in fire frequency due to a warming climate. It is widely assumed and predicted by some models that the feedback between the two is negative, that recently burnt areas are less flammable than those long unburnt so that as fire frequency is increased, the mean flammability of the community decreases (Fernandes and Botelho 2003), restoring balance to the system. This is, however, grounded in a questionable understanding of forest fuels (Zylstra 2011a) and known to be incorrect for a number of communities where recently or frequently burnt areas have been found to be equally or more flammable than long-unburnt sites (Fernandes and Botelho 2003). In some cases this positive feedback has encouraged instability in the community, ultimately leading to the production of more flammable alternate stable states (e.g. Odion *et al.* 2010; Lindenmayer *et al.* 2011; Blackhall *et al.* 2012).

The flammability of subalpine forests and woodlands dominated by Snowgum *Eucalyptus pauciflora* and Alpine Snowgum *E. niphophila* species is important not only for the conservation status and risk management of those forests, but also because these communities surround the only alpine areas of the Australian mainland. Consequently, changes in the flammability of subalpine communities will also affect the frequency and intensity at which fire enters the very limited (250 km$^2$, Costin *et al.* 2000) alpine communities.

Snowgum forest is found predominantly in the mainland Australian Alps, a section of the Great Dividing Range in the south-eastern corner of the country, stretching south from the Australian Capital Territory (ACT) through New South Wales (NSW) and into Victoria (Vic). These forests and woodlands occur at the highest elevations of forested land in the country between approximately 1450 and 1830 m above sea level (Costermans 1994; Costin *et al.* 2000) with mixed lower occurrences (Gellie 2005), and together with the alpine communities occupy most of the area above the winter snow line (Green and Osborne 2012). Much of this area is protected via a series of National Parks forming the Australian Alps National Parks.

Although patchy, all evidence to date suggests that fire has been a rare form of disturbance in the subalpine and alpine areas until its frequent introduction by European graziers (Zylstra 2006). The trees themselves are easily stemkilled by even low-intensity fire because of their thin bark (Good 1982; Gill 1997), so that regrowth occurs via basal sprouting (Pickering and Barry 2005).

As mountainous snowfields represent such a small component of a dry continent, subalpine and alpine areas support significant high conservation species (Costin *et al.* 2000; DEC NSW 2006; Green and Osborne 2011) with approximately 30% of taxa in treeless areas endemic to the Alps (McDougal *et al.* 2007), and provide critical catchment values to south-eastern Australia (Schreider *et al.* 1997). In this latter regard, Snowgums perform an important role in increasing the overall annual precipitation via intercepting and condensing mist and fog (Costin and Wimbush 1961).

Climate change is broadly expected to increase the frequency of weather conducive to fire through much of Australia (Williams *et al.* 2001; Pickering *et al.* 2004; Hennessy *et al.* 2005; Lucas *et al.* 2007; Pitman *et al.* 2007) and temperatures across alpine and subalpine areas have on average increased by 0.74°C between 1950 and 2007 (Gallagher *et al.* 2009). Although precipitation levels appear to be similar, the maximum snow depth has decreased in concert with a dramatic increase in maximum winter temperatures at indicator sites in the NSW Snowy Mountains (Davis 2013), resulting in a steady decrease in snow metre-days (Green and Pickering 2009) and a 40% decrease in spring snow depth between 1962 and 2005 (Nicholls 2005). Under best case scenarios the duration of snow cover is expected to decrease; however, under more severe warming, elevations around 1400 m are expected to be nearly snow-free by 2030 (Whetton *et al.* 1996), producing a much longer snow-free period in which fires can spread.

The alpine area is one of particular concern from a climate change perspective (Hughes 2010) and it is possible that the negative effects of increased fire frequency on catchment (e.g. White *et al.* 2006) and habitat values (e.g. Green and Sanecki 2006) may be one of the more significant impacts on these communities. Management to minimise this impact has been recognised as a priority for the alpine area (Green 2008); however, the planned introduction of fire is widely seen as the only viable mechanism for reducing landscape flammability (Gill 2008). If the feedback between fire and flammability is positive, prescribed fire will increase the impact rather than decrease it.

The question of feedbacks in this community was addressed using deterministic modelling in a recent study (Zylstra 2011b), which predicted that for the subalpine site examined, fire in fact produced a marked positive feedback with flammability so that increased fire frequency in those forests would result in their increased flammability.

For the site examined (Figs. 1 and 2), the modelling indicated three stages of recovery from fire (Fig. 3); these were:

1. A 'young' period where dense grass and shrub growth coupled with the absence of a tree canopy that could mitigate wind speeds produced fast spreading fires that were easily suppressed due to low flame heights.
2. A 'regrowth' period where the regenerating Snowgum coppice began to separate from the lower shrubs into a distinct canopy stratum. During this period, crown fires became less frequent so that the average rate of spread decreased, but produced significantly greater flame heights when they did occur, increasing mean suppression difficulty.
3. A 'mature' period where the canopy was fully developed and sufficiently separated from the lower strata so that crown fires were rare, producing much slower and more easily suppressed fires.

Translating these or any other factors into a physically meaningful concept of flammability is not straightforward (Fernandes and Cruz 2012). Although individual components such as ignitability, combustibility and sustainability can be characterised using field measurements (Gill and Zylstra 2005), the combined measure of flammability is an emergent property that depends on the interaction of these component measures with the environment that they are impacting. Whether the faster fires of young fuels or the more difficult to suppress fires of regrowth fuels should be considered more flammable cannot be derived objectively from these outputs alone; however, it can be observed that both metrics are low for a very brief period immediately following fire and for an extended period in the mature forest. Such a pattern of

**Fig. 1.** The six year-old Snowgum site examined in Zylstra (2011b)

**Fig. 2.** The adjacent 50+ year-old Snowgum site examined in Zylstra (2011b)

a primary inhibition period immediately after fire followed by a period of peak flammability and then a secondary inhibition period of indefinite duration was described by McCarthy *et al.* (2001) as a 'moisture model', contrasting with three models of negative feedback (linear, Olsen and logistic).

This paper examines the available empirical evidence of fire in Snowgum forest and woodland in order to test the validity of the deterministic predictions against what Zedler and Seiger (2000) termed the 'fuel-age paradigm' where flammability accumulates with time since fire. As the modelling is restricted to a

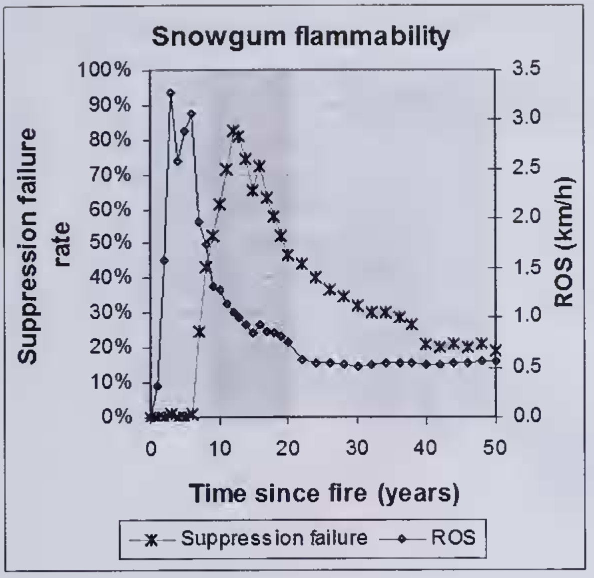


**Fig. 3.** Mean summer fire behaviour modelled for one summer in Snowgum forest on a 17 degree slope. The three areas of shading delineate the 'young' period of fast, easily suppressible fires, the 'regrowth' period of moderate speed, difficult to suppress fires and the 'mature' period of slow, much more easily suppressed fires.

single site and the ways that flame height and rate of spread combine to produce overall burnt area are unknown, the comparison can only be qualitative.

## Methods

The relationship of time since fire and flammability was tested by comparing the Probability of Ignition at a Point (PIP, after Gill *et al.* 2000; McCarthy, Gill and Bradstock 2001) with time since fire for the 190000 ha of Snowgum forest/woodland mapped across the Australian Alps National Parks (Fig. 4). Time since either planned or unplanned fire was calculated for burnt areas using the 53 years of continuous mapped fire history covering the period 1957 to 2010, sourced from the relevant land and fire management agencies in each state. Vegetation mapping used Ecological Vegetation Classes (DSE 2010) for Victorian parks, and alliances in NSW and the ACT as classified by Gellie (2005). The analysis used a spatial resolution of 100 m cells and was conducted using ArcView GIS.

Due to the fact that PIP is an emergent property of the speed at which a fire spreads and the difficulty of its suppression, it was considered to be a meaningful measure of forest flammability. That is, the flammability of a forest or fuel age is defined by the mean annual area burnt by unplanned fire, where efforts have been made to suppress these fires.

Results were standardised by the percentage of each age class present in the landscape, and derived values were then divided by the mean value for all fuel ages to give the flammability ratio FR or the expected area burnt each year in an age class compared to the average across all age classes. An FR of two for example means that for a given year, fire is likely to burn twice as much of that age class compared to the average across all age classes, and can be described as being twice as flammable as the average.

Mathematically this is:

$$FR_n = \bar{x}(FR_{n,1957\text{-}2010})$$

Where $FR_n$ is the flammability ratio for forest of age $n$ years, and $FR_{n,1957\text{-}2010}$ are all flammability ratios for age $n$ for the years 1957–2010.

$$FR_{ny} = \frac{AF_{ny}}{\bar{x}(AF_{1\text{-}53,1957\text{-}2010})}$$

Where $FR_{ny}$ is the flammability ratio for forests of age $n$ years in the year $y$, $AF_{ny}$ is the area factor for forest of age $n$ in year $y$, and $AF_{1\text{-}53,1957\text{-}2010}$ refers to all area factors for forests aged 1 to 53 years, from all years 1957–2010.

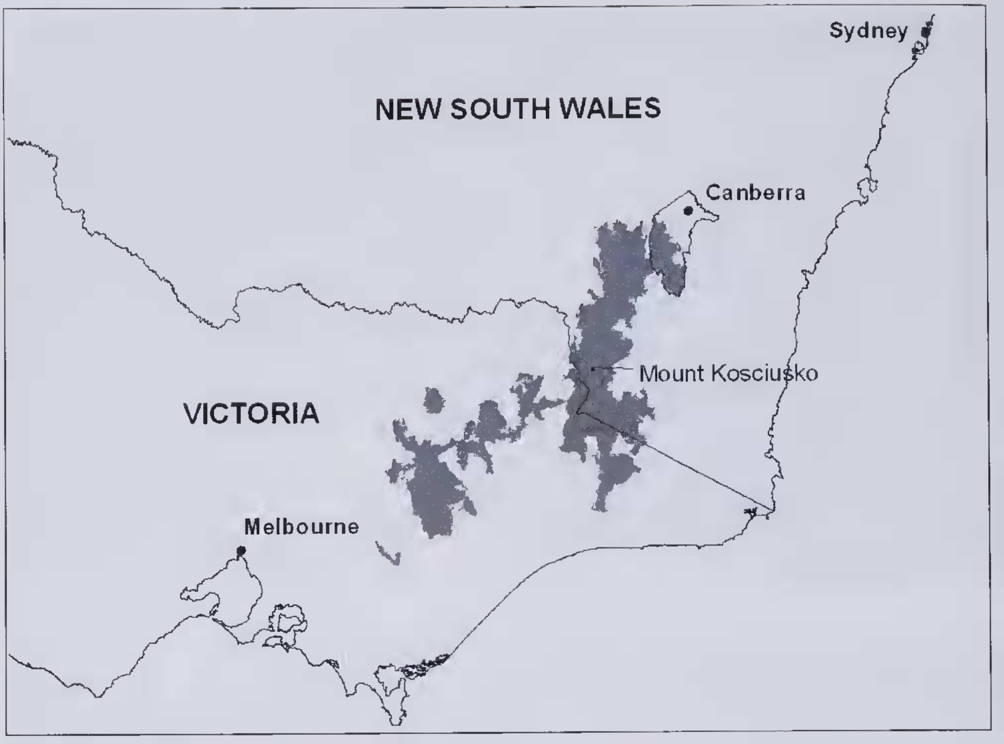


Fig. 4. The Australian Alps National Parks

$$AF_{ny} = \frac{AB_n \bar{x}(AK_{1\text{-}53})}{AK_n \Sigma(AB_{1\text{-}53})}$$

Where $AB_n$ is the area of forest aged $n$ years burnt in a given year, $AK_n$ is the total known area of forest aged $n$ years and $AF_{1\text{-}53}$ and $AB_{1\text{-}53}$ are all of the $AF$ and $AB$ values for all ages within the year being examined.

In order to test the prediction of Zylstra (2011b) that Snowgum flammability develops in the three stages of young, regrowth and mature forest or the pattern described as a 'moisture model', breaks between young, regrowth and mature age classes were identified using a $t$-test to determine where the greatest statistical difference occurred between the flammability of one age range to that of the following age range. An age range was determined to be an inhibition period if the mean FR for the range was less than unity, and the modelling was validated if the regrowth class was more flammable than either young or mature forests. The feedback was designated as positive if the FR in mature forests was lower than it was in the combined younger stages.

## Results

A total of 159 records were used to calculate FRs for each age class, with the oldest mapped age being 48 years and the first unplanned fire to burn fuels of a known age occurring in 1965. The mean FR for each age range is shown in Fig. 5.

Three stages of flammability were significant, as expected from the modelling. A weak primary inhibition period marked the young phase (FR = 0.85, $p = 0.10$), followed by a brief period of heightened flammability during the regrowth phase (FR = 2.58, $p = 0.10$) and an indefinitely lasting and much more pronounced secondary inhibition period during the mature phase (FR = 0.59, Table 1).

A second analysis compared the combined young and regrowth phases with the mature phase (Table 2), finding greater significance ($p = 0.05$). In this case, subalpine forest and woodland had an FR of 1.38 for the first 14 years after fire.

## Discussion

Over the past 53 years of consistent records and where young and regrowth Snowgum has been

Table 1. Mean flammability ratios for a three-period model, showing significance and the age in years marking the end of the period

| Young | | | Regrowth | | | Mature |
|---|---|---|---|---|---|---|
| FR | Significance | Max age | FR | Significance | Max age | FR |
| 0.85 | 91.80% | 10 | 2.58 | 94.90% | 14 | 0.59 |

Table 2. Mean flammability ratios for a two-period model, showing significance and the age in years marking the end of the period

| Young | | | Mature |
|---|---|---|---|
| FR | Significance | Max age | FR |
| 1.38 | 96.20% | 14 | 0.59 |

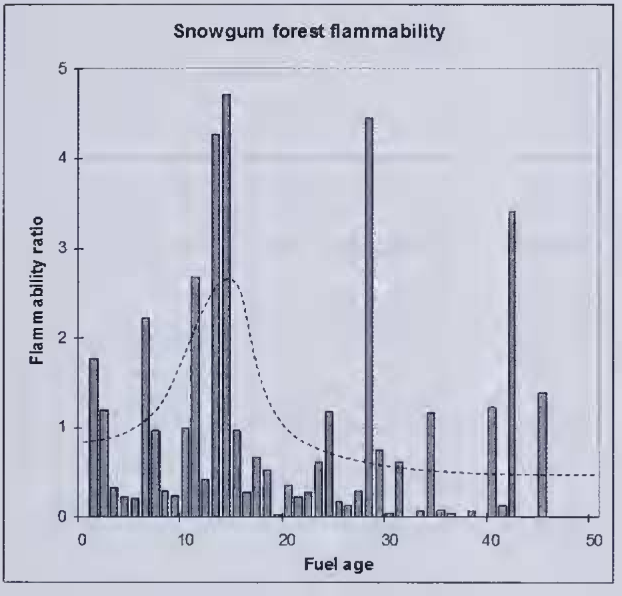


Fig. 5. Flammability ratios for sub-alpine forest and woodland. The broken line is indicative only, and approximates the trend of the data for a three-period model.

present in the landscape, fires have burnt these age ranges approximately 2.3 times more often than they have mature forest, demonstrating a pronounced positive feedback. The modelling indicates that while faster spreading fires in young grassy fuels caused some increase in final burnt area, the main increase was due to the difficulty of suppression resulting from greater flame heights in regrowing coppice and shrubs.

The flammability of Snowgum forests is likely to influence not only the forests but also the treeless alpine and frost-plain areas they surround. Considering the pre-European scarcity of fire in the area (Banks 1988; Zylstra 2006) and the lack of fire adaptation in the component species (Pickering *et al.* 2004), the impact of any increase in frequency on the 200+ endemic plant species of the treeless areas (McDougall and Walsh 2007) may be significant, as may be impacts on catchment qualities and infrastructure associated with electricity production and ski resorts, which constitute major industries in the region (DEC NSW 2008). Large fires in the Alps also affect the local tourism economy, with some towns for example reporting a complete loss of trade for up to two months during the 2006–07 alpine fires of Victoria (Sanders *et al.* 2008).

While the study demonstrated a clear relationship between fire and flammability in these forests, the effect of specific fire severities, frequencies or seasons was not examined. The modelling suggested that the way in which fires affected future flammability most strongly related to the way that they modified forest structure to affect the likelihood of crown fire development. This likelihood could increase when the tree crowns were scorched or burnt so that regrowing crowns were closer to the ground, or where fire promoted shrub growth so that the ground fire was closer to the tree canopy. Previous studies demonstrate that burning Snowgum without affecting the forest in this way is operationally very difficult due to the sensitivity of the trees (Good 1982; Gill 1997), and the effects of repeated fire on community structure are largely unknown. It is possible, however, that specific conditions may permit this, as it is also possible that in some cases the identified trend does not hold and mature Snowgum forest is more flammable than recently burnt areas. The findings of this study demonstrate that these are minor exceptions, and their validation of the FFM support its viability as a tool for investigating such exceptions.

Overall, if fire is either intentionally introduced to Snowgum forest more frequently or facilitated more often by changes in the climate, there is greater than 95% likelihood that these areas will become more flammable, not less. For example, burning mature forests on a 14-year cycle will more than double the average size of bushfires in the treated area compared to the previous mature state. Under most conditions, fires in the treated area will be both faster spreading and more difficult to suppress; however, modelling suggests that under the most extreme conditions mature forests will at times produce the largest crown fires.

Due to the widespread assumption (Fernandes and Botelho 2003) and prediction of a widely used model (Zylstra 2011b) that recently burnt forests will be less flammable than mature forests, the modelling of increased flammability using the FFM represents a 'risky' prediction (Popper 1957), and its validation by this study underpins the capacity of the FFM to model such trends.


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